20-GHz optical pulse source based on cascaded electroabsorption modulators

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A high-quality low-timing-jitter 20-GHz optical pulse train is generated by using two cascaded sinusoidally driven electroabsorption modulators (EAMs) at very low bias voltage of −0.8 V in conjunction with a tunable distributed feedback (DFB) semiconductor laser. An approximate transform-limited optical pulse, with the pulse width less than 7 ps, the spectral width of 0.3 nm, and the side-mode suppression ratio (SMSR) above 20 dB, is obtained by tuning the optical delay line.

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The stable generation of high-repetition-rate ultrashort optical pulse streams is required for such applications as optical time-division multiplexing (OTDM), soliton transmission, and optical sampling systems, etc.[1−6]. In ultrahigh-speed all-optical communication systems, the optical source used at the transmitter should be capable of generating high-repetition-rate ultrashort optical pulses with low timing jitter and frequency chirping. Gain-switched lasers[7,8] and mode-locked lasers[9−12] have been mainly used to generate such short pulses. Gain switching can easily generate short optical pulses, but it involves problems of large-frequency chirping and large timing jitter owing to the dynamic carrier density distribution. Mode-locked lasers can provide much shorter pulses at high repetition rate but be very sensitive to ambient temperature change and vibration, and also involve difficulties in controlling the repetition cycles of the generated pulses. The technique using single sinusoidally driven electroabsorption modulator (EAM) has been employed to overcome these difficulties. The advantages of this scheme are high speed, low chirping, low timing jitter and repetition-frequency tunability, while the pulse duration is comparatively wide. In order to reduce the pulse width, high reverse bias of about $6-9$ V[13] and modulation voltage of $10-15$ V are required, but this causes high optical power loss and decreases the side-mode suppression ratio (SMSR) for strong electrical absorption effect.

We propose a scheme to generate optical short pulses by using double sinusoidally driven EAMs with very low reverse bias of 0.8 V and a tunable optical delay line, which can availably decrease the optical pulse width and increase the SMSR of the EAM pulse generator. The comparatively wide optical pulse from the first EAM driven by 20-GHz radio frequency (RF) signal is delayed by the tunable optical delay line passing through the second EAM. The optical pulse with the width less than 7 ps, SMSR above 20 dB, and timing jitter lower than 600 fs, is generated due to nonlinear attenuation effect and switched effect. And the total optical loss of this system is lower than 11 dB.

Figure 1 shows the experimental setup for the cascaded EAM pulse generator system. The tunable distributed feedback (DFB) semiconductor laser (EXFO FLS-2600B) is in conjunction with two cascaded EAMs (OKI OM5753C) which are respectively driven by the amplified (electrical amplifiers (SHF, 100AP)) 20-GHz RF signals coming from two branches of the splitter connected with the RF generator (Agilent E8257D). The tunable optical delay line between the two EAMs is used to adjust the time when the optical pulse from the first EAM reaches the second EAM in order to produce short pulse. To measure the waveform of EAM laser's optical pulses, the pulse stream of this laser output is fed into a 50-GHz photodetector (PD) (U2T XPDV2020R). A high-speed oscilloscope (Agilent 86100C) of 70-GHz electronic bandwidth is connected with the ultrafast PD in order to display the pulse waveform. An optical isolator (shown in Fig. 1) is employed to prevent the feedback of external light into the tunable laser. The bias voltage of EAM laser (not displayed in Fig. 1) is a very important factor for our experimental results.

In EAM pulse generator system, the pulse width and amplitude are very sensitive to EAM bias voltage. Figure 2 shows the pulse width and rising time as functions

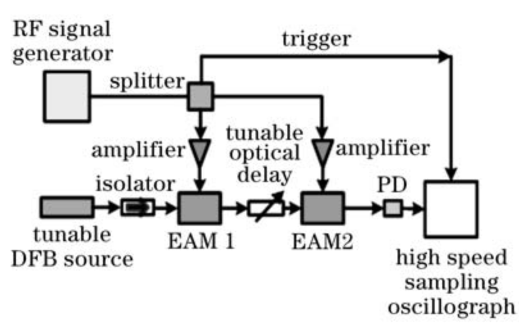

Fig. 1. Experiment setup of the cascaded EAM pulse generator system.

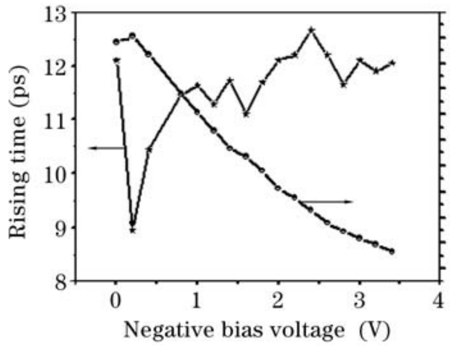

Fig. 2. Pulse width and rising time dependent on the bias voltage using single EAM.

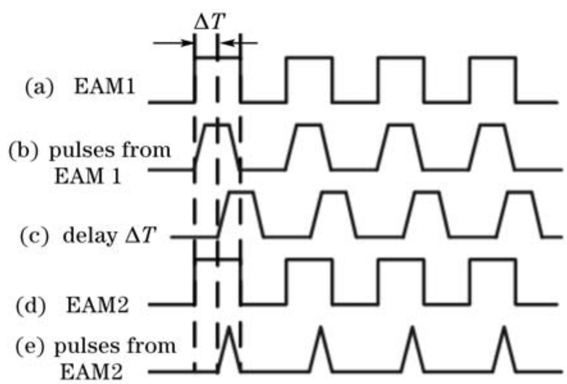

Fig. 3. Theory diagram of pulse generator system using two cascaded EAMs.

of the bias voltage using single 20-GHz RF signal-driving EAM. We can find that the pulse rising time is comparatively short and the width is comparatively wide at lower bias voltage (for example lower than 1.5 V), and the optical loss is relatively low at lower bias voltage using a single EAM, which can exactly be used to generate short pulses in the cascaded EAM pulse generator system. The theory diagram of two cascaded EAMs pulse generator system is shown in Fig. 3. Figures 3(a) and (d) are respectively switched doors of EAM1 and EAM2 driven by RF signal under low bias voltage condition, Fig. 3(b) is the comparatively wide optical pulse generated by EAM1 connected with the tunable DFB semiconductor source, Fig. 3(c) displays the pulse train delayed by the tunable delay line with Δt spacing, Fig. 3(e) is the ultrashort optical pulse stream output of the pulse generator system. It should be mentioned that the optical delay line's delay space (Δt) also has great effect on the pulse width, during the experiment we always tuned it at the optimized position, in other words, it made the laser output the shortest pulse.

The variation of pulse width and rising time with the bias voltage at the 5 V (P-P) modulation voltage is shown in Fig. 4, which did not optimize the parameters of the laser system. Figures 5(a)—(d) show the optimized pulses by changing the modulation voltage at bias voltages of −0.4, −0.8, −1.8, and −3.0 V, respectively. The measured pulse widths were 13.6, 10.9, 14.6, and 12.8 ps, and the measured rising time values were 8.3, 7.3, 10.6, and 9.3 ps, respectively. In order to obtain the actual pulse width (ΔT) generated by the cascaded EAM pulse generator system, we deconvolved the response of

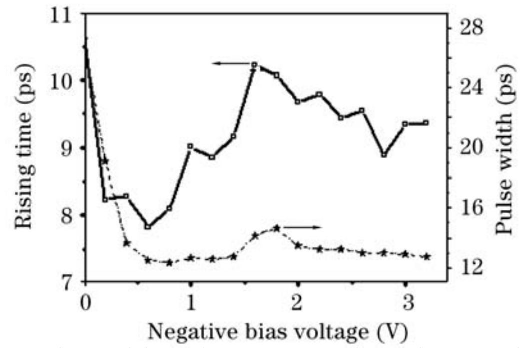

Fig. 4. Pulse width and rising time dependent on the bias voltage using double EAMs.

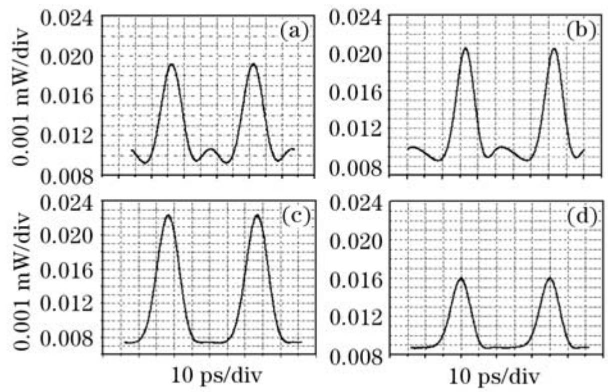

Fig. 5. Pulses obtained with different bias voltages of (a) −0.4 V, (b) −0.8 V, (c) −1.8 V, and (d) −3.0 V.

measuring system from the measured pulse width ($\Delta T_{\rm m}$), assuming that both the generated pulse and the detection system have Gaussian frequency response. From the 3-dB bandwidth of 50 GHz of measuring system, the full-width at half-maximum (FWHM) of impulse response ($\Delta T_{\rm s}$) of detection system is calculated to be 8.8 ps, assuming time-bandwidth product of 0.44 for Gaussian frequency response. From the deconvolution using $\Delta T^2 = \Delta T_{\rm m}^2 - \Delta T_{\rm s}^2$, we deduce that these actual pulse widths are 10.4, 6.4, 11.6, and 9.2 ps, respectively. The optical power loss will be increasingly serious when the bias voltage increases (see Fig. 5(d)), at the same time the SMSR of pulse decreases. The SMSR of the EAM pulse generator system at low bias voltage is above 20 dB (see Figs. 5(a)—(c)).

The cascaded EAM pulse generator system is not sensitive to the variation of injection optical wavelength. Figure 6 shows the spectrum of the pulse generator

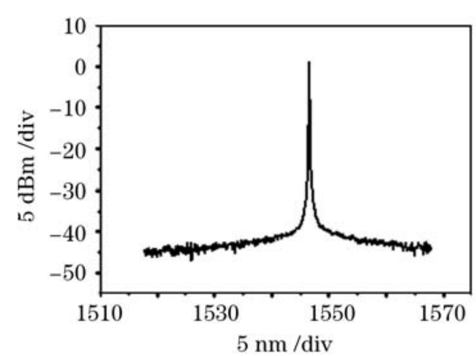

Fig. 6. Spectral waveform of pulse at 1548 nm.

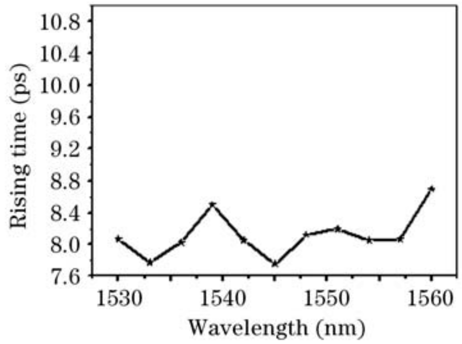

Fig. 7. Rising time of pulse versus injection wavelength in the cascaded EAM pulse generator system.

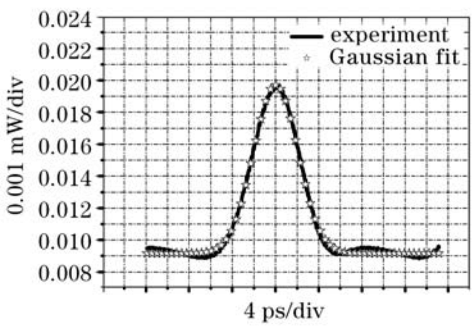

Fig. 8. Curve of the single pulse at −0.8-V bias voltage.

system at 1548 nm, whose FWHM is about 0.3 nm. Figure 7 shows the optimized pulse rising time at the different wavelengths from 1530 to 1560 nm, and the change of pulse rising time is not over 1 ps at the different injection wavelengths, this characteristic is very useful in OTDM communication system. The time bandwidth product of the cascaded EAM generator system at 1548 nm is 0.4479, close to the value of 0.44 of the transform-limited pulse (shown in Fig. 8).

In conclusion, we demonstrated the stable high-speed optical pulse generator system by using one optical delay line and two cascaded EAMs. For the generated pulses, the repetition frequency is 20 GHz, the pulse width is about 7 ps, the time bandwidth product is about 0.44, the SMSR is above 20 dB, and the total loss is lower than 11 dB.

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